ARGRAVES

Methods of
Reinforcing Concrete

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METHODS OF RE-INFORCING CONCRETE

BY

ARLOW J. ARGRAVES

THESIS

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C O L L E G E   O F   E N G I N E E R I N G

May 25, 1907.

This is to certify that the following thesis prepared under the immediate direction of Mr. Harry Gardner, Instructor in Civil Engineering, by

ARLOW J ARGRAVES

entitled DISCUSSION OF APPROVED METHODS OF REINFORCING CONCRETE

is accepted by me as fulfilling this part of the requirements for the Degree of Bachelor of Science in Civil Engineering.

Ira O. Baker

Head of Department of Civil Engineering

INTRODUCTION

Object of Thesis.—

On account of the comparative newness of the art of reinforcing concrete for building purposes, new ideas concerning the processes are constantly being presented, and experiments upon the finished product performed. The object of this thesis is to bring together, in so far as possible, information regarding the different methods of concrete reinforcement.

Reasons for Concrete Reinforcement.—

Concrete has a low tensile strength and consequently was first used to resist only compressive stresses in foundations, walls and so forth. By imbedding steel in concrete its

ability to resist shear and tension is greatly enhanced and thus the uses to which it may be put are greatly multiplied. Compressive stresses are generally successfully resisted by the concrete itself, though sometimes reinforcement is supplied to resist even those stresses.

__Methods of Reinforcement.__

The methods of reinforcing concrete are almost innumerable. The most convenient classification, however, seems to be as follows: Bar, Net, and Expanded Metal systems, each of which may be classified almost indefinitely.

I BAR SYSTEM.

The system of reinforcing concrete by means of bars is one of the most common. Various [illegible] are used and suggest [illegible] [illegible] [illegible] [illegible], but

for the purpose of this dis-
cussion is made chiefly, then,
with reference to the shape
of their cross sections.

A - Plain Round Rods

The plain round rod was the first shape to be used as a reinforcing material, and there are many advantages to its credit. It is easily attained in the market in mild or high carbon steel and is as cheap as any other shape. The chief objection brought against round bar reinforcement is that the rods will slip in the concrete because of insufficient bond. This has been proved by experiments performed by Mr. Harding of the Chicago, Milwaukee, & St. Paul Railway and described in a paper presented before the Western Society of Engineers, October 25, 1905. Reinforcement with round bars is made in many different ways,

dependent upon various combinations of the rods. Among the many systems of round bar reinforcement are:

1. The Cummings System.

In this system round bars of different lengths having their ends bent to an incline and formed into a loop, are used. The Cummings system differs from others in using a self-locating chair, as the rod is shown in figure 1. The chair is

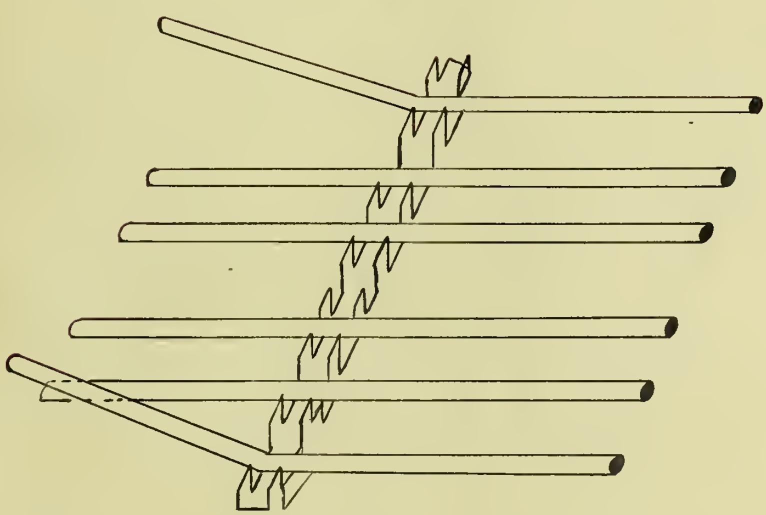


Fig. 1 - Cummings Chair.

stamped from strips of sheet or

band steel having regular projections which are bent up to space the bars. Reinforcement for compression is made by using "Cummings Self-Centering Steel Hoops and Verticals," the hoops being made of flat steel bent in a circle with the ends riveted together and one end bent outwardly at right angles to the hoops. The spacing verticals consist of light steel shapes punched with small holes for staples by which the hoops are quickly fastened to the verticals.

The advantages claimed for this system are: 1. The exact distribution of the steel for tensile stresses, the rods being equally spaced. 2. The commercial steel shapes are plain and can be readily obtained. 3. The shapes are comparatively simple and so can be had at minimum cost. 4. The bond is good because of

the bars being hooked at the ends.

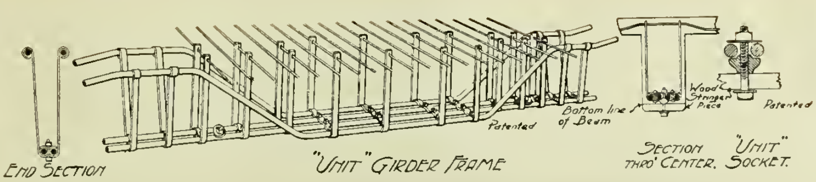
A good example of the Cummings system is the Taylor-Wilson Manufacturing Company's Machine Works at McKees Rocks, Pennsylvania. Its length is 160 feet, width 102 feet, and height 57 feet, and it is supported by columns 20 feet between centers, the columns being 20 inches in diameter and reinforced by Cummings self-centering steel hoops. The continuous girders above the columns carry a traveling crane, weighing 60 tons with load, and capable of developing a speed of 350 feet per minute, and a trussed arch roof of reinforced concrete covers the main isle.

Bibliography:
"Reinforced Concrete" - Cummings Structural Concrete Company, Pittsburg, Pa.

2. The Unit System.

The "Unit" system of reinforcing

concrete is not obtained by the use of a single trussed non-deformed bar but is a combination of round bars built in the form of beams or girders about which the concrete is packed. The invention of the system culminated from the fact that most reinforced concrete is put up by unskilled labor and placing the reinforcement as a unit eliminates to a great extent the personal equations of the workmen. The bars in this system are fastened together as shown in figure 2.



"UNIT" GIRDER FRAME (PATENTED)

Fig. 2

The following is a report of a "Fire, Load and Water Test," on a "Unit" Concrete Steel Frame Co. floor, conducted,

June 16, 1905 at Columbia University, under the supervision of the engineering staff of the New York and Philadelphia Bureaus of Buildings. Deflections are in sixteenths of an inch. Those observations preceded by the minus sign indicate rising tendencies and the rest falling tendencies.

Table of Results.

	Time. June 16	West Beam Deflections			Middle Beam Deflections			East Beam Deflections		
		1	2	3	1	2	3	1	2	3
Start of Fire	10:45	0	0	0	0	0	0	0	0	0
	11:00	-1	-1	-1	-2	-2	-1	-1	-4	2
	11:15	-3	-2	-3	-4	-5	-1	-3	-8	3
	11:30	-4	-5	-3	5	-8	-5	5	-8	5
	11:45	5	-8	-5	-8	-10	-7	6	-9	6
	12:00	-5	10	-6	-8	-11	-8	1	12	7
	12:15	-1	-10	-7	-9	-12	-9	-8	13	8
	12:30	-8	-10	-8	-9	-10	10	-9	12	8
	12:45	-9	-8	-10	-9	-8	10	10	10	0
	1:00	-11	-5	-11	-11	-5	-12	11	-7	11
	1:15	-12	-4	-12	12	-1	-12	13	6	12
	1:30	-12	-2	-12	-12	0	-12	4	5	13
	1:45	-13	-2	-13	-13	1	13	15	5	15
	2:00	-14	0	-14	-12	5	13	15	-2	-14
	2:15	-15	3	-14	-13	9	13	16	2	13
	2:30	-15	5	-15	13	13	13	16	6	13
End of Fire	2:45	-16	9	-16	13	17	12	17	10	13
		June 17. floor cooled, nearly all load removed								
	9:00	-1	17	-2	0	24	0	-1	20	0
		Load of 650 pounds per square foot.								
	3:30	3	32	1	3	38	4	3	32	3

Corrected Total Deflections

for middle of beams taking into consideration the rise of ends of beams.

June 16 2:45	W. B	M. B.	E. B.
	$1\frac{9}{16}''$	$1\frac{27}{32}''$	$1\frac{9}{16}''$
June 17 9:00	$1\frac{5}{32}''$	$1\frac{1}{2}''$	$1\frac{9}{32}''$
3:30	$1\frac{7}{8}''$	$2''$	$1\frac{13}{16}''$

<u>Note</u>: The results were obtained as follows: In all beam deflections when the ends rise and the middle falls; the deflections of the middle were added to the mean of the rises of the ends. When both middle and ends fall – subtract the mean deflection of the two ends from the deflection of the middle.

The following advantages are claimed for the "Unit" system: 1. Economy of time in placing since the frame is delivered as a unit. 2. Ease with which it can be inspected before concrete is laid. 3. The reinforcement

is not easily moved by the tamping of the concrete. 4. When the beam is finished it can be used to support ceilings, partitions, shafting, steam pipes, gas or electric fixtures, fans or motors without the use of expansion bolts.

This system is patented by the "Unit" Concrete Steel Frame Co. of Philadelphia from whom further information may be obtained.

3. Hennibique System

The Hennibique system was invented by Mr. François Hennibique a prominent French engineer and one of the most successful concrete-steel builders in Europe.

This system is principally used for beams and girders though it is also applied to walls and stairways. The tension in a beam is taken by plain round rods

in the lower portion; one rod runs the full length of the beam parallel to the lower surface, while another inclines upward at about one third of the span from the supports. These inclined rods are intended to take shear. There are also rods in the upper part of the beam which are connected to those below by means of stirrups of flat iron. [illegible] ends of the rods are split and these Y-shaped [illegible] when tamped in [illegible] concrete tend to increase the bond. The Hennebique beam is compared to an I-beam so far as the distribution of stresses is concerned and "the designing engineers follow the methods of the bending moment of a plate girder permitting of the application of ordinary computations." It is a homogeneous beam and may be given any desired form. The use of rods in the concrete is

[illegible] between beams, the reinforce-ments being placed alternately near each side of the wall which is from 8 to 12 centimeters thick.

An arch bridge over the Vienne River at Chatellerault, France, is a good representative of the Hennebique system. This bridge consists of three spans; the central one being 164 feet long with a rise of 15 feet. The roadway is supported by four arch ribs 20 inches deep.

Bibliography: "Cement and Concrete," p. 335 — Sabin; "Practical Applications of Reinforced Concrete" Eng. Mag. Jan. 1902; "Architects and Builders Handbook" Kidder.

4. Coignet System

The Coignet system was invented by M. Edmund Coignet of France. He was one of the earliest workers in re-

[illegible] concrete Coignet is a civil engineer and large contractor in France and it was by his efforts, assisted by M. de Tedesco, that scientific experiments were performed which enabled a rational theory of the stresses in reinforced concrete to be established. He first put forth his ideas in 1888 before the "French Society of Civil Engineers". His plan is to reinforce concrete beams in both the upper and lower portions with plain round rods. In this respect this system resembles the Hennebique system. The stirrups used in the Coignet system to connect the upper and lower rods are simply round rods bent over the longitudinal ones and wired in position with annealed wire. These stirrups are for the purpose of taking shearing stresses as well as bracing the other rods. Wire-net

ing is sometimes used instead of the round rod stirrups but that does not seem to be the general practice. Another advantage due to the method of connecting the upper and lower rods is the resistance to slipping of the reinforcement through the concrete. In this system mild steel is used having a tensile strength of 58,000 pounds per square inch and an elongation of 22 per cent in 8 inches while the concrete is generally a 3:5:10 mixture weighing 150 pounds per cubic foot. The Coignet system is not limited to beams but is used in floor slabs, pillars etc., the slabs being 1 inches to 5 inches thick, the principal rods extending between the nearest supports, and the secondary bars of smaller cross-section lying normal to the principal ones, all being connected

of small wires. Posts, pillars, and columns made according to the [illegible] system may have square or round cross-sections.

To give an idea of the efficiency of this system, consider the results of tests made at the "Testing Establishment of the British Fire-Prevention Committee". These tests were made upon a reinforced concrete floor supported by reinforced concrete beams. The [illegible] consisted of 3 bays each 15 feet long by 7 feet, 5 inches wide, making 334 square feet of floor area. Each intermediate beam had 2 steel rods 16 feet long by $1\frac{1}{2}$ inches in diameter in the lower part and 2 - $\frac{9}{16}$ inch rods in the horizontal plane, the upper and lower reinforcement being connected by loops and ties. The floor was 6 inches thick and the depth of the floor beams below-

the floor was 12½ inches thick. Cinder concrete was used, the floor being dried for 40 days, after which a load of 280 pounds per square foot was applied, and the temperature raised to 1800°-2000° F. Deflection began within 15 minutes after the gas was lighted, the total being 5.6 inches in 3 hours. Water was then applied and the concrete on the soffit was washed away - leaving the horizontal rods exposed. When the load was removed, cracks showed in the direction of the beams and the permanent set was $5\frac{7}{16}$ inches. Neither fire, smoke nor water passed through the floor.

Bibliography:-

"The Coignet Reinforced Concrete System" - Am. Arch't & Bldg News, Sept. 29, 1906; "Fire Tests with Floors" - Engng. July 13, 1906.

5. Siegwart System.

This is a ferro-concrete floor beam system, and was developed at Lucerne France. It differs from most others in that the beams are made at the factory and need no elaborate centering when placed. they are transported as ordinary I-beams. The beams are hollow, the reinforcing rods being in the top and bottom.

Tests were made upon a Siegwart floor built of beams 9.84 inches wide and 8.66 inches deep, side walls 1.18 inches thick, bottom walls 1.50 inches thick, and the upper walls 1.57 inches thick, the reinforcing rods being .275 inches in diameter. The span was 13.45 feet C-C. the floor being designed for 81.9 pounds per square foot. It was loaded $2\frac{1}{2}$ times the load designed for, the deflection being .0397 inches and the perma-

ment set 0.2 millimeters. There were no cracks.

The advantages claimed for the Siegwart system are: 1. Lightness because of being hollow, 2. They are poor conductors of sound, this being quite a factor to be considered in manufacturing buildings, 3. Economy of time on account of not being compelled to wait for concrete to harden in place, 4 Ease of transportation.

These beams are not yet very widely used. A description is given in the Engr., Jan 29, 1904

6. Cottancin System.

Still another system in which round rods are used is the Cottancin system. It was invented by a French Engineer whose name it bears. The reinforcement consists of a combination of steel rods into a mesh form, the size of the

[illegible] to the load to be placed upon the structure. There are two special forms of the Cottancin reinforcement. Figure 3 shows what is known as the "lattice-pattern reinforcing skeleton", which consists of round rods bent at certain distances, thru 180 degrees with rods interlaced at right angles. Figure 4 shows

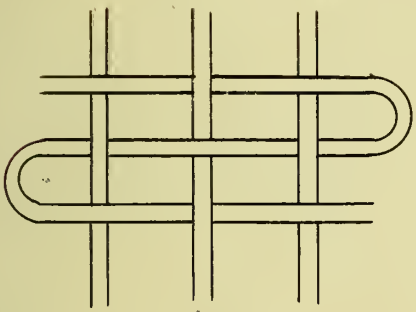


Fig. 3

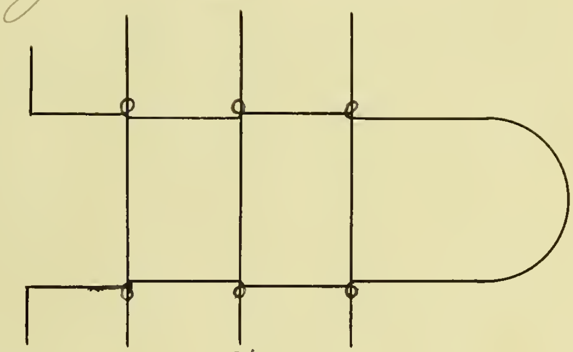


Fig 4.

the "continuous skeleton with the woven spiral". In each case the mesh is made large so that the concrete can be firmly tamped into the interstices. On account of the ease with which the rods can be bent the Cottancin can be used in artistic structure. It is used however more largely in foundation several cases of which are described in "Concrete-Steel" by W. N. Twelvetrees. This system has been quite successfully

[illegible] use has not increased as rapidly as some others, in the United States.

Bibliography:

"Practical Applications of Reinforced Concrete," Eng. Mag., Jan., 1902

B. Bars of Rectangular Cross-Section.

This division of the bar system includes a considerable variety of shapes. Among those most commonly known are:

1. Johnson Corrugated Bar.

The Johnson corrugated bar is square with frequent corrugations surrounding it, as shown in figure 5. High carbon steel is used of

Fig. 5. Johson Bar.

55000 pounds elastic limit and 100,000 pounds per square inch tensile

strength. The chief reason for the introduction of this bar for re-inforcing concrete was the lack of bond between smooth bars and concrete. To quote Professor Talbot from his text, " concrete beams, bulletin number 14, page 25: "The value of bond in resistance will depend upon the smoothness of the bar, the uniformity of its diameter, the adhesive strength of the concrete, and the shrinkage grip developed in setting." On page 44 of the same bulletin in reference to tests made on beams with smooth bar reinforcement, he says: "Owing to the extremely smooth surface and uniform cross-section of this steel, these beams did not develop as much strength as those reinforced with mild steel, the tensile strength being well below the elastic limit of the material. The beam failed by slipping of the rods followed by vertical and longitudinal cracks."

The advantages claimed for the Johnson bar are 1. that a higher working stress can be used than would be adopted for soft steel bars, because the elastic limit is very high. Consequently proportionately less metal is required. 2. Cracks in the concrete cannot penetrate to the indented bar as long as the stress in the steel is inside of the elastic limit. 3. Reduction of cross-section, due to tensile stress inside of the elastic limit, in no way reduces the effective grip on the concrete. 4. Vibrations and shocks do not impair the bonding. 5. Being formed by rolls, while hot, the bars are all alike, the shape of each piece in no way depending upon the skill of some workmen. 6. The bar is adaptable to any form of construction.

The following tests were made by Professor F. H. Constant.

Type of Bar	Size	Age of Cem. days	Min. Net Cross-Sec. sq. in.	Imbedded Length-Ft.	Load	Unit Stress.	
Johnson	$\frac{3}{4}$"	28	0.31	8.25	31,620	102,000#	*
"	"	"	"	8.62	12,360	39,900#	†
"	"	"	"	8.21	18,120	58,500#	‡

* Concrete Split. Mixture = 1:2:4
† Concrete Split. Mixture = 1:3:6
‡ Concrete Split. Mixture = 1:4:8

A notable example of the use of the Johnson Bar is the Galveston Sea Wall. It is 3 miles long, 6 inches higher than the highest flood, being 17 feet high, 16 feet wide at the base and 5 feet wide at the top. It is entirely reinforced with 10 foot Johnson bars 1¼ inches square. The wall is built on round piling foundation 45 feet long, the piles being 12 inches at top and 17 inches at the base.

Bibliography:

"The Johnson Bar" Lond. Eng. June 8, '06; "Catalogue" Expanded Metal and Corrugated Bar Co., St. Louis, Mo.

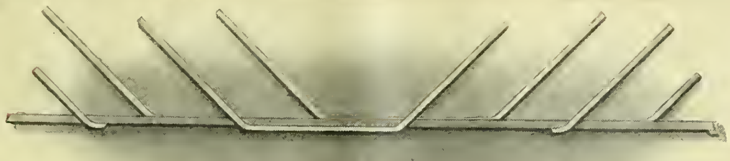
2. Kahn Trussed Bar.

The Kahn trussed bar is a horizontal, flanged bar with the flanges sheared up at intervals. There are two general types of the Kahn bar; the Regular type as shown in figure 6, and the Alternating type

as shown in figure 7.

Kahn Trussed Bar, Regular Type.

Fig. 6



Alternating Type

Fig. 7

The distinguishing feature of the Kahn bar is the provision against shear, or tension and shear together. A beam when loaded has a tendency to shear along a line making some angle with the vertical. The Kahn bar was invented with this principle in mind, the horizontal part taking the tensile stresses and the sheared up flanges taking the bearing stresses.

Some of the advantages of the Kahn bar are: 1. Economy of material, the same bar resisting tension, compression, and shear, 2. Simplicity and rapidity of construction.

3. Good bond, the metal being distributed pretty uniformly.

Some of the disadvantages are: 1. Detailed shop work for each size of girder, 2. Inconvenience in shipping on account of turned up flanges, 3. Difficulty of tamping concrete.

Among the many examples of reinforced concrete in which the Kahn bar was used is the "Marlborough Blenheim Hotel" of Atlantic City, N.J. The Kahn bar was used in all the columns, girders and floors. The main body of this building is nine stories high, while including the dome there are thirteen stories. The length is 560 feet and the width varies from 60 feet to 200 feet. The whole structure was erected in less than six months, while if other materials had been used it is estimated that it would have taken at least 12 months. In appearance the building is imposing and the details of the interior, such as

cantilever balconies, turrets, domes, arches, etc. show the adaptability of reinforced concrete to architectural effect.

Bibliography:

"Cement and Concrete" Sabin; "Pamphlet" Trussed Concrete Steel Co., Detroit, Michigan.

3. Plain Square Bar.

The plain square bar is not used nearly as much as formerly. The chief objection to it is the sharp corners which tend to crack the concrete when a load is applied.

C. Irregular Cross-Section

All bars that are not included in plain round rods and bars of rectangular cross-section, we will classify as bars of "Irregular Cross Section". This system of reinforcement includes an almost infinite number of shapes, some of which are very similar but are slightly changed

to suit the fancies of different men. Each however has certain advantages claimed for it. Among the principal bars of irregular cross-section are:

1. Ransome Bar.

The Ransome bar was one of the first steel rods shaped so as to give a mechanical bond with concrete and was invented by Mr. Ernest L. Ransome, who was the first man to design and erect a reinforced concrete bridge in America. The shape is obtained by twisting uniformly any bar with square cross section the primary object of twisting being to give a continuous bond instead of one that is effective only at intervals. The twisting also increases the reliability that can be imposed on the metal since tests show that it raises the elastic limit fifty per cent and the ultimate strength thirty five per cent, and it is also a test of

the quality of the steel since any imperfections will show when the rod is twisted.

Following is a table comparing the Ransome bar with plain bars:

Size "□	E.L. #/□"		Ult. Str. #/□"		Price per 100#	
	Plain	Twisted	Plain	Twisted	Plain	Twisted
1/4	46170	62,350	57,800	86,100		
1/2	----	60120	----	86,350	$1,30	$2.10
3/4	34,840	56,120	59,200	85,240	1.73	2.53
7/8	39,700	56,150	62,100	84,730	1.50	1.80
1	----	55,760	----	84,275		
1 1/4	----	55,450	----	83,150		

For a bars smaller than 3/4 inch $.80 is added to Pittsburg price of plain rods f.o.b. The prices given are relative and not exact and the above Elastic limits and ultimate strengths are taken from the record of tests made at Columbia University by Professor Ira H. Woolson.

The Ransome bar is adapted for use where any other bar can be

used. It is used to quite an extent in chimney construction, an example of which is the smoke stack of the Pacific Electric Co., Los Angeles, California. It is 180 ft. high; the base being built 15½ feet in the ground and the inner diameter being 11 feet. At a height of 51 feet the stack assumes a circular form. Another form of Ransome construction is to be seen in the railway trestle at Perth Amboy, New Jersey. The bents are reinforced with $\frac{3}{8}$ inch Ransome bars with no longitudinal bracing. One of the largest reinforced concrete buildings in this country is the Robert Gair Company Factory, Brooklyn. It occupies an area of 600 x 200 ft. and ~~as~~ consists of eight stories and a basement, with a total floor area of 170,000 square feet.

Following are some cuts showing the method of laying the Ransome bar and also some (tests) by the Turner Construction Company.

Bibliography:

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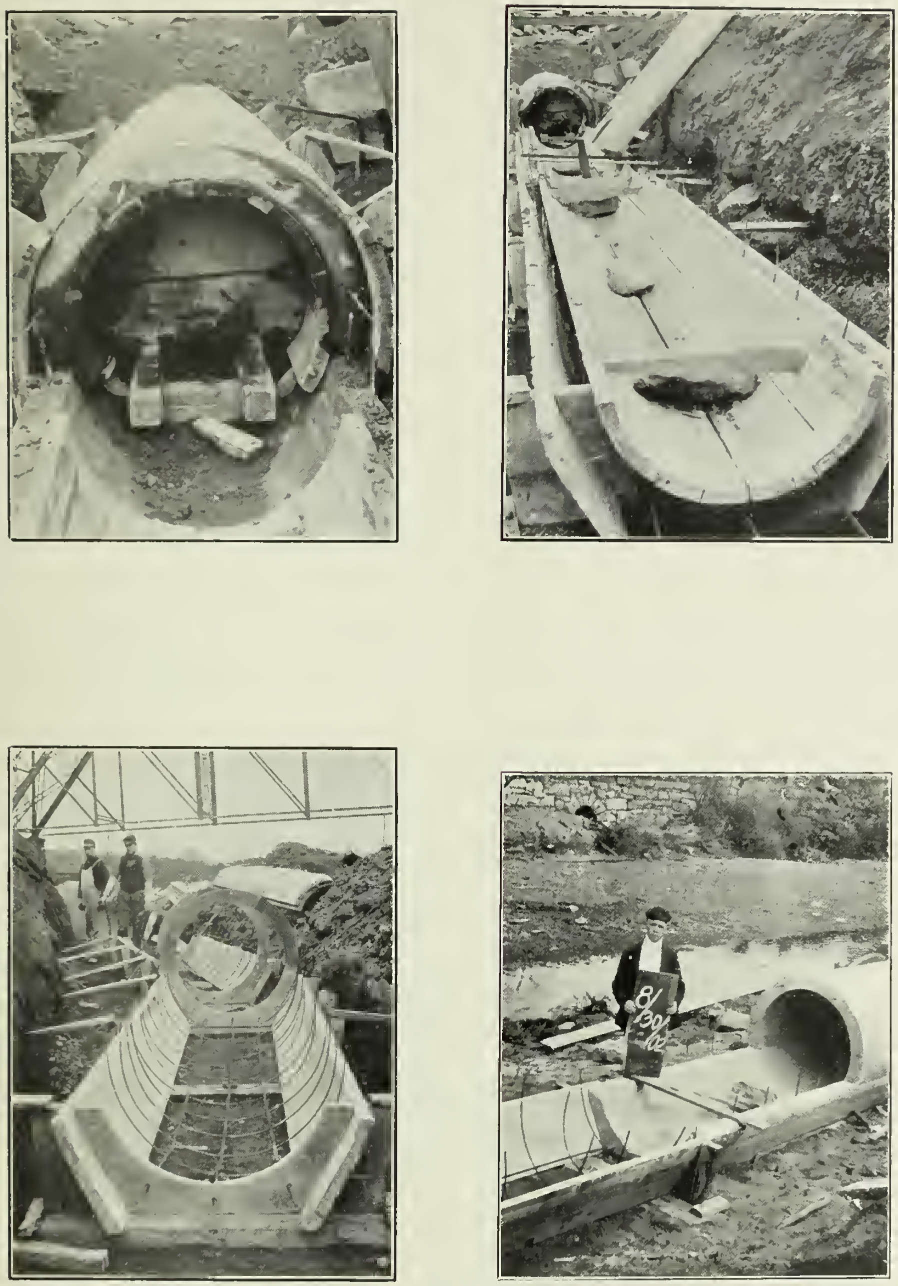
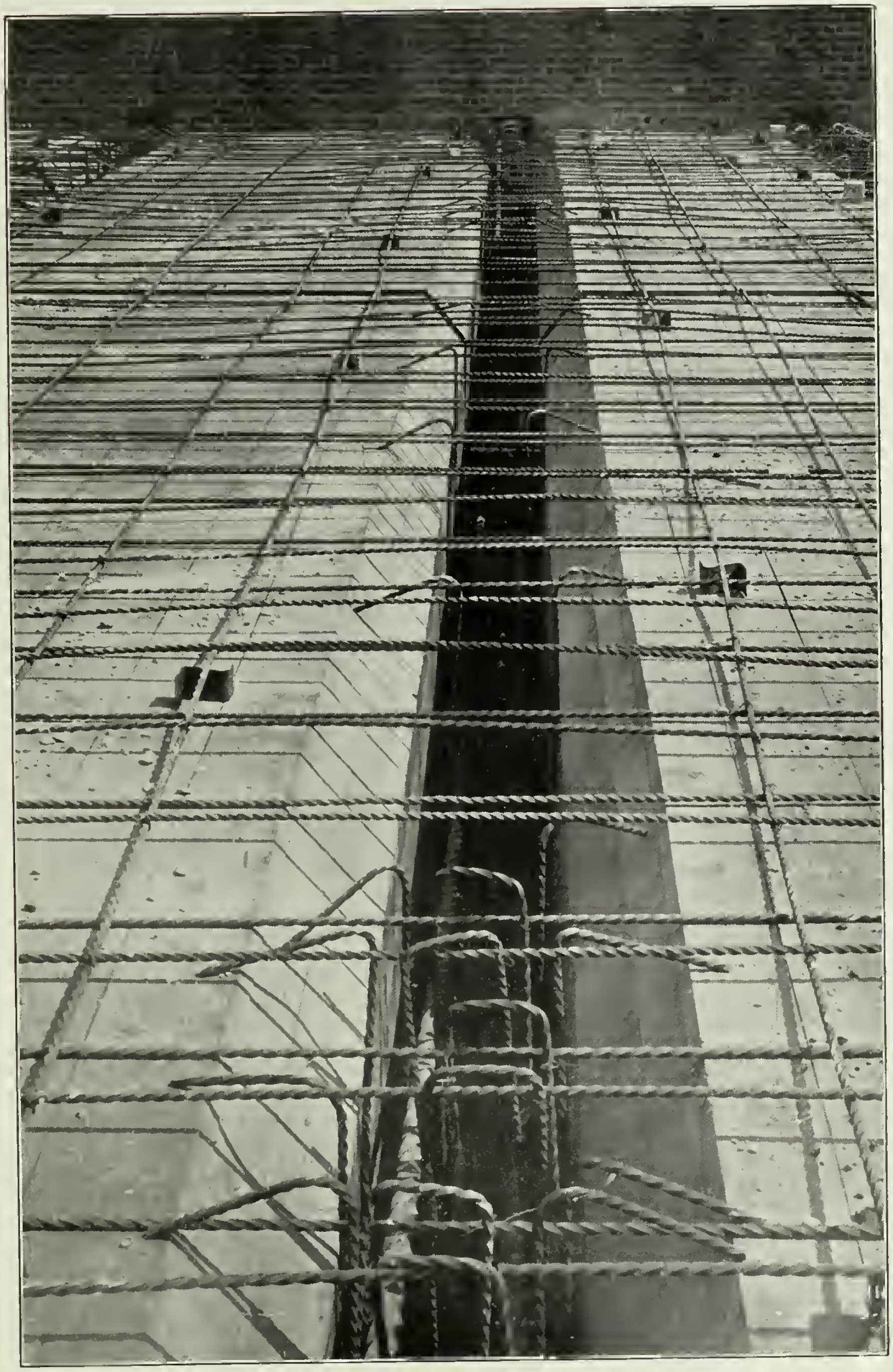


Concrete sewer, Ransome System. Built by Westinghouse, Church, Kerr & Co., at Scranton, Pa.
Designed by Turner Construction Co.

The South Pub. Press, 195 Fulton St., N. Y.



Wm. Higginson, Architect. Erected Summer, 1905.

Brooklyn Riding and Driving Club Garage. Showing wood centering and twisted steel bars for 50-foot floor span.

"Forms of Concrete Reinforcement" - Iron Age, Jan. 11, '06; "Reinforced Concrete" Turner Construction Co., 11 Broadway, N.Y.; "Hand-book" - William B. Hough Co., Chicago, Ill.; Eng. News, Mch 12, 1903; Eng. News, Apr. 2, 1903; Eng. News Apr. 9, 1903; "Concrete Metal Construction" - Jol. of Eng. Soc., Feb. 1901.

2. The Melan System.

The Melan system of concrete reinforcement consists in imbedding I-beams in concrete with out any cross-rod connections; the beams being arranged parallel. The beams used in arch construction are bent at the mill at a cost of ½¢ per pound. This system seems to meet with special favor among the Austrian Engineers who have performed many tests upon it. The results of some of the tests made by the Austrian Government comparing the Melan system with others and also with simple concrete and brick-in-concrete are given below.

Results of Austrian Tests

Material	Span Ft.	Rise in	Thk's of Crown in.	Am't of Steel #/□'	Breaking Load- #s
Brick-in-Cement	$13\frac{1}{3}$	$15\frac{3}{4}$	6	—	321.5
Concrete	"	"	4	— —	787.3
Monier	"	"	$2\frac{3}{8}$	8	839.7
Melan	"	11.0	$3\frac{1}{8}$	1.4	3360.0
Wuensch	16.4	20.0	4.0	1.5	1010.0

At Stockbridge, Mass., the Melan arch of 100 foot span, 10 feet rise, 9 inches thickness at the crown and 30 inches at the haunches; 7 in. X 15 lb. I-beams were used, spaced 28 inches apart and the concrete was a 1:2:4 mixture with Aalberg cement. The foundation is partly on stone and partly gravel and the arch is unsymmetrical on account of the different heights of the banks. The cost of the arch was $1,475.

The principal advantages of the Melan construction are: 1. Economy of iron and 2. Great strength. For proof of both see table above.

Bibliography:

"On the Melan System" - R.R. Gaz.

Apr. 13, 1894, "The Wuensch and Melan Systems of Fire-Proof Floor Construction" - Eng. News (Apr. 12, 1894; "Melan Arch Bridge" - Eng. News, Oct. 3, 1895; "Tests on Monier and Melan Arches" - Eng. Mag. Vol. 10, 1895.

3. Columbian System.

The Columbian system is under the control of the Columbian Fireproofing Company of Pittsburg, Pa. It is used principally in fire-proof floor construction, the characteristic feature being the double cross-shaped bar as shown in (a), figure 8. The Columbian floors are made in two styles, "long

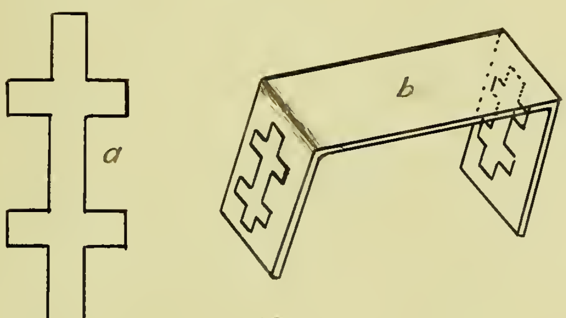


Fig. 8.

span", and "short span". In each case I-beams are used and the bars are placed at right angles to them, being spaced about 24 inches apart. In the "long span"

construction the bars are hung to the I-beams by means of stirrups. The sketch (b) [illegible] 8 represents one of these stirrups. Angles are sometimes used, while in the "short span" construction stirrups are always used.

The following table gives the [illegible]fe carrying capacity of Columbian floors as compiled from actual tests.

Long Spans					Short Spans			
Distance between Supports	Uniform Load. Bars 24" C-C.				Distance between Supports	Uniform Load Bars 24" C-C.		
	6" Bars	5" Bars	$4\frac{1}{4}$" Bar	$3\frac{1}{2}$" Bar		$2\frac{1}{2}$" Bars	2" Bars	1" Bars
Ft.	lbs.	lbs.	lbs	lbs.	Ft.	lbs.	lbs.	lbs
12	412	362	312	275	5	400	340	290
13	346	306	265	235	6	275	242	200
14	296	260	230	200	7	200	178	140
15	256	226	200	175	8	150	135	110
16	225	200	175		9	125	100	70
17	200	175	125		10	100	70	
18	177	150			11	80		
19	140	100						
20	100	80						
Concrete Thickness	$7\frac{1}{2}$"	$6\frac{1}{2}$"	$5\frac{3}{4}$"	5"		4"	$3\frac{1}{2}$"	3"

After a [illegible] water test of 3 hours duration made on a floor in Boston of 11 ft - 3 in. span, a load

of 1650 pounds was carried with a deflection of only $1\frac{3}{8}$ inches.

Bibliography.

"Reinforced Concrete" Buel & Hill; "Kidder's Handbook", and Eng. News Nov. 21, 1901.

4. Wuensch System.

This system was invented by Robert Wuensch in Hungary in 1884. The reinforcing steel is T shaped in cross section and may be either rolled T-shapes or built up ties, but the latter are the ones most used. They are made of angles placed back to back.

The Wuensch system is used chiefly for arch bridges and has been tested to a greater extent by Austrian engineers than of any other. As used for arches the upper reinforcement is horizontal while the tie used for the lower reinforcement conforms to the curved line of the soffit. The upper and lower ties are fastened together

at the crown, and at the abutment are connected by vertical members, these verticals being connected at their base by channels running transversely to the direction of the arch.

This method is said to be cheap, costing 30 percent less than brick, and is very efficient in strength as is shown by the results of tests made on a 16.6 foot arch by Hungarian engineers. The arch was designed to carry 80 pounds per square foot.

Table of Results

Total Load	Load lbs. per sq. ft.	Deflections Quarter Point ins.	Mid Point ins	Quarter Point ins.
2844	88			0.04
5049	105		.04	0.04
8356	258		0.16	0.16 *
11673	360	0.04	0.27	0.27 †
16082	410		0.59	0.55 ‡
18287	565	0.75	2.64	1.97 §
33101	1010		5.75	

* Fine crack began to show.
† Cracks unchanged
‡ Cracks open to .08 inch

& cracks increased slowly to neck down.

Up to 1894 there were only six highway bridges built in Hungary by the Wünsch system, the spans being from 13 feet to 55 feet. Since then many have been built, among them being one at Neuhausel which consists of six spans of 56 feet each with a rise of 3.7 feet and a thickness at the crown of 9.8 inches and at the springing line of 54.3 inches.

Bibliography.

"Cement and Concrete" - Sabin;
"Concrete and Iron Arches" - R. R. Gaz. Apr. 13, '94;
"The Wünsch and Melan Systems of Fire-Proof Floor Construction" - Eng. News Apr. 12, '94.

5. Weber System

The Weber system is used in chimneys only and is patented by the "Weber Steel-Concrete Chimney Company," 924-934 Marquette Building, Chicago — the first American patent being obtained December 29, 1903.

The foundation of a Weber Chimney is made of 1:3:5 concrete reinforced by two layers of T steel of small size, the distance between the layers varying with the size of the chimney and the carrying capacity of the soil. The lower bars are placed diagonally while the upper ones are placed parallel with the sides of the foundation. The vertical rods forming the reinforcement for the shaft extend down into the foundation and are bent in order to secure good anchorage.

The chimney shaft consists of two parts, a lower double shell and an upper single shell, these being united at the offset which is at about one third of the height, but varying somewhat with the nature and heat of the chimney gases, purpose of chimney, and the height of the smoke entrance. The thickness of the inner part of the double shell is generally four inches

and of the outer part six to twelve inches, while that of the single shell is from four to ten inches. There is a dead air space between the two parts of the double shell allowing the inner part to expand and giving it protection from the weather and at the same time furnishing protection to the outer part from heat. An expansion joint is provided where the two shells unite. No gravel or stone is used above ground, the mixture being 1 Portland to 2 sand. The steel used is from 16 to 30 feet long and lap not less than 24 inches, the joinings being very irregular to prevent any unusual weakness, and the circumferential spacing is 18 inches. In exceptional cases "all single" or "all double" shell chimneys are built. The work of erection is done from the interior, no external scaffolding being needed.

The advantages of the "Weber" chimney claimed by its makers are as follows: 1. "The Weber" chimney

is monolithic without any joints or interruptions. The air has no disintegrating effect as on steel chimneys". 2. It is air-tight, of uniform inside diameter and almost perfectly smooth giving higher working capacity than others. 3. It can be erected more rapidly than brick or steel and the materials of construction are easily obtainable in any locality. 4. It occupies less space than a steel or brick chimney since the base is not nearly as large. 5. It is lighter than either brick or steel." The difference in weight seems to be chiefly in the base. 6 "Its outside appearance is better than brick or steel on account of its outline, color etc." As to this the best looking chimneys are those that taper on the exterior toward the top and the Weber chimney does not.

The highest chimney of this type is one built for Colusa Parrott Mining and Smelting Company, Butte, Montana its height being 350 feet and its inside diameter 18 feet.

1028

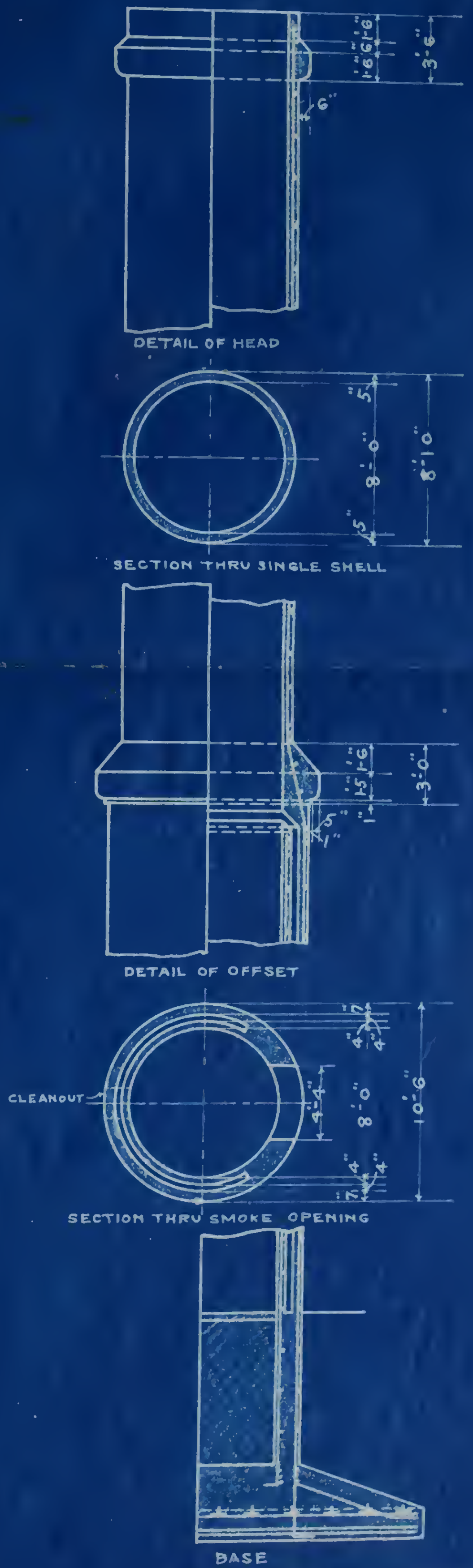
WEBER STEEL-CONCRETE CHIMNEY COMPANY.

CHIMNEY

175 FT. HIGH AND 8 FT. 0 INS. DIAM.

FOR

C.R. MAKEPEACE AND CO.
NEW BEDFORD, MASS.



FOUNDATION AND VERTICAL BARS ARE $1\frac{1}{4}$"x$1\frac{1}{4}$"x$\frac{3}{16}$" T'S
RINGS ARE $\frac{5}{8}$" ROUND BARS SPACED 18" ¢

ENGINEERING DEPARTMENT.

CHICAGO, NOV. 6, 1906. J.W.
Changed 11/9/06

DO NOT SCALE THIS BLUE PRINT.

1028

The adjacent blue print gives the details of a Weber Chimney.

Bibliography.—

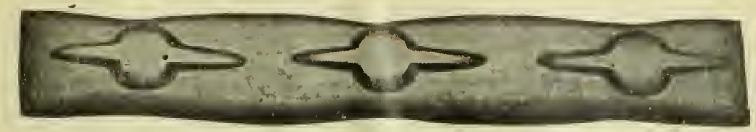
"Weber Chimneys"—Weber Steel-Concrete Co., Chicago, "Architects and Builders Pocket-Book"—Kidder.

6 Thacher Bar System.

This system, like all other bar systems is characterized by the use of a particular kind of bar for which various advantages are claimed.

The Thacher bar is a bulbed bar and was originally rolled from the round bar at regular steel mills but the "Concrete Steel Engineering Co." rolls them at special rolling mills. The sectional area of the Thacher bar is irregular but uniform in variation and changes by gradual curves avoiding all sharp corners, giving it the appearance as shown in figure 9. Sizes are obtained from $\frac{1}{4}$ inch to 2 inches in diameter. A table showing ultimate strength, weight

per linear foot etc. is given in Kidder's "Architects & Builder's Pocket-Book" part of which table will be given here.



THACHER PATENT BARS

Fig. 9

Diameter inches	Area sq. in.	Weight lbs per lin. ft.	Ultimate Str. Med. Steel
$\frac{1}{4}$	0.047	0.16	3,000
$\frac{1}{2}$	0.18	0.61	11,500
$\frac{3}{4}$	0.41	1.39	26,200
1	0.71	2.42	45,400
$1\frac{1}{4}$	1.10	3.74	70,400
$1\frac{1}{2}$	1.56	5.30	99,800
$1\frac{3}{4}$	2.08	1.01	133,100
2	2.65	9.02	169,600

The advantages of the Thacher bar as a reinforcing material are 1. There being no sharp corners, it does not have a tendency to crack the concrete. 2. There is good bond due to the irregular surface given. 3. It can be used for any construction that any deformed bar of a similar

nature is used for, being easily cut to various shapes. 4. It is as easily shipped as any other.

A representative of the Thacher bar construction is found in a reinforced concrete bridge at Trinidad, Colorado and which is described in the Engineering Record for February 10, 1906. There are 2 70 foot arch spans the rise being 7 feet and the clear width between parapets 64 feet including an 44 foot roadway and 2-10 foot side-walks. The arches were designed for a live load of 125 pounds per sq. ft., the crowns being 14 inches deep and the haunches 3 feet thick. Forty-four pairs of $1\frac{1}{8}$ inch bars were used longitudinally and Twelve pairs of $\frac{3}{4}$ inch bars transversely.

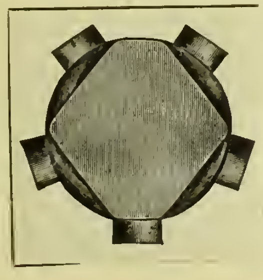
Bibliography.

Iron Age for Jan. 11, 1906; "Architects and Builders Pocket-Book"-Kidder; "Reinforced Concrete"- Buel and Hill.

7. Lug Bar.

The Lug bar is a new shape for reinforcement, gotten out by "The General Fire-proofing Company" of Youngstown Ohio. It is practically the same shape as the Ransome bar with the addition of the lugs which are intended to still further increase the bond to the concrete. The lug bar is also twisted cold to increase the elastic limit and as a test upon the quality of steel used. "All bars must bend cold, 180° to a diameter equal to the thickness of the bar without sign of fracture on the outside of bent portion". They vary in size from $\frac{1}{4}$ inch bars to $1\frac{1}{2}$ inch bars, variations being by $\frac{1}{8}$ inch.

Further detailed information as to tests etc. can be had of the manufacturers. A cut of this bar is given in figure 10



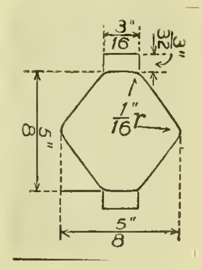


Fig. 10 - Lug Bar.

II NET SYSTEM

The Net System of reinforcing concrete is the oldest system known to exist its first application being the construction of a small row boat by Lambot and exhibited by him in 1855 at the Paris Exposition. The skeleton of the boat was formed of a wire-netting imbedded in concrete. It is still used in the city park of Miraval in central France. François Monier claimed to have been the discoverer of the advantages of combinations of steel and concrete and was issued patents covering all uses of steel and concrete together. However these patents were afterwards invalidated when it was proven that he was not the first inventor of concrete-steel. The invalidation of Monier's patents enabled others to present their ideas along that line and consequently many methods of reinforcing followed.

1. Monier System.

The Monier system of concrete reinforcement was one of the earliest if not the first system in which the net reinforcement was widely used. It was invented by Jean Monier of Paris and consists of small steel rods placed at right angles to each other and wired at the points of intersection. No attempt is made to increase the adhesion of the steel and concrete by deforming the rods. This system is designed to resist both longitudinal and transverse tensile stresses. On account of the shape of the cross section of the rods used the Monier system might properly be classified as a plain-bar system but since the general form of the reinforcement is a net we will classify it as belonging to the net system.

The genuine Monier system as applied to arches consists of the use of only one netting in the intrados, though two nets are

sometimes used.

The conclusion drawn from tests on "Melan and Monier Arches" by Austrian engineers are as follows. 1 Monier arch with one net is not as superior as is claimed by supporters of the system; the Monier netting should not be used for floors; the concrete used is more expensive than that used for most other systems; and two nets are impracticable for short spans.

The results of some of the Austrian tests were given in the discussion of the Melan system.

Some of the advantages claimed for the Monier system are:

1. "Maximum carrying capacity with minimum weight of structure".
2. "Economy of space". It has no advantage in this respect over any of the net systems.
3. "Rapid construction." The fact that each intersection must be wired by hand does not affirm this claim.
4. "Cheapness". The rods are cheaper than

as former ones but the concrete is generally more expensive and the work of placing is greater since the points of intersection are not mechanically connected as in some systems.

5. "Cleanliness".

6. "Adaptability to different shapes".

5 & 6 are obviously true.

An example of Monier Construction is the Illinois Steel Company's concrete storage tanks which are described in the Engineering News for December 11, 1902. Five-eighths inch steel rods were used, tied with #18 wire in the base, and electrically welded #9 wire with a 1 inch by 4 inch mesh was used in the walls. Another example of Monier construction is the highway bridge over Nador Canal at Szarbogard, Hungary. The span is 50 feet and the rise is 7.06 feet.

Bibliography:—

"Monier Construction" – Journ. of W. S. of C. E's. June, 1900; "Tests on Arches by Monier System" – Eng. News Vol. 35, 1896; "Description of Monier Arches" – Eng. News Vol. 1, 1893; "Concrete and Iron Arches" – R.R. Gaz. 4/13/'94

2. Roebling System.

The Roebling system is noted chiefly for its use in floors, though it is also used in columns, ceilings and girders. As employed for floors for steel buildings it consists of arches of woven wire stiffened by inter woven steel rods spaced about nine inches apart. The arches spring from beam to beam and rest on top of the lower flanges, the rise in the arches being about three inches less than the depth of the supporting I beams. On these arches Portland concrete is deposited, making a pleasing monolithic construction admirably adapted for a fire-proof floor. The ceiling consists of a system of supporting rods fastened to the lower flange of the I-beams by patent clamps. Beneath the supporting rods and securely laced to them is the Roebling Standard Wire Lathing. This lathing is a wire mesh, the wires being

woven at right angles. One fourth inch rods are woven into the wire lathing, crossing the supporting rods at right angles. The construction of both floor, ceiling and column by the Roebling method is clearly shown by figure 11.

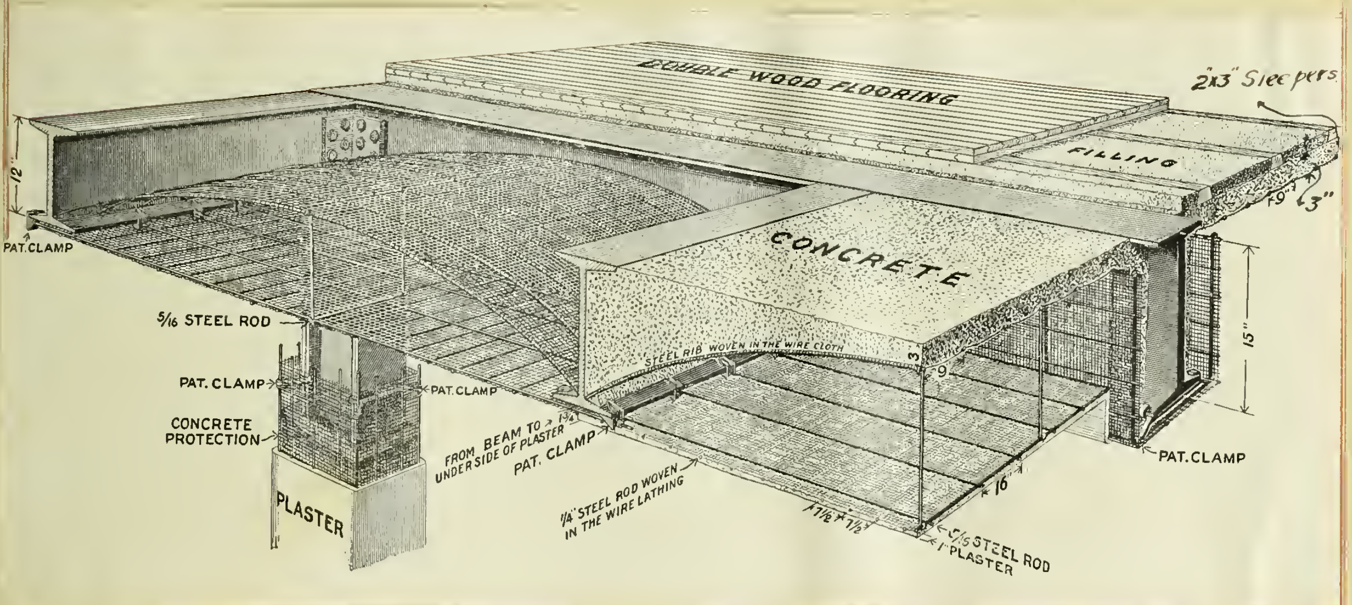


Fig. 11 - Roebling Construction.

Some of the advantages of the Roebling system are:

1. "Saving in steel and economy in construction". It is said that the cost of this construction is 10-20 percent less than any other that the Boston Building Department has approved.
2. Greater strength and stiffness on account of the homogeneous structure.

floor arches consisting of a number of assembled parts invariably settle to some extent, and this settlement tends to produce cracks. Since these floors practically become monolithic when the concrete hardens they cannot settle as long as the I-beams hold; hence cannot crack.

3. Increase in Elasticity. The arch form gives a floor a greater tendency to return to its original shape when a load is removed.

4. Increase in fire-proof qualities. A fire and water test was made on a Roebling floor on October 28, 1896 by the New York Building Department. The floor was subjected to a fire test for five hours, at a temperature of 2000°-3000° F., and then immediately cooled by a stream from a regulation fire engine. It was afterwards tested with a load of 4[illegible] pounds per square foot. The effect of the tests on the concrete is described thus in the official report: "The concrete arch proper seemed not to be affected in any

way by the fire and water".

Probably the largest building in which the Roebling system of reinforced concrete construction was used, is the Ansonia Apartment Hotel, 73rd St. and Broadway, New York. It is the largest apartment hotel in the world and has a floor space of 554,600 square feet in which the Roebling system was used throughout.

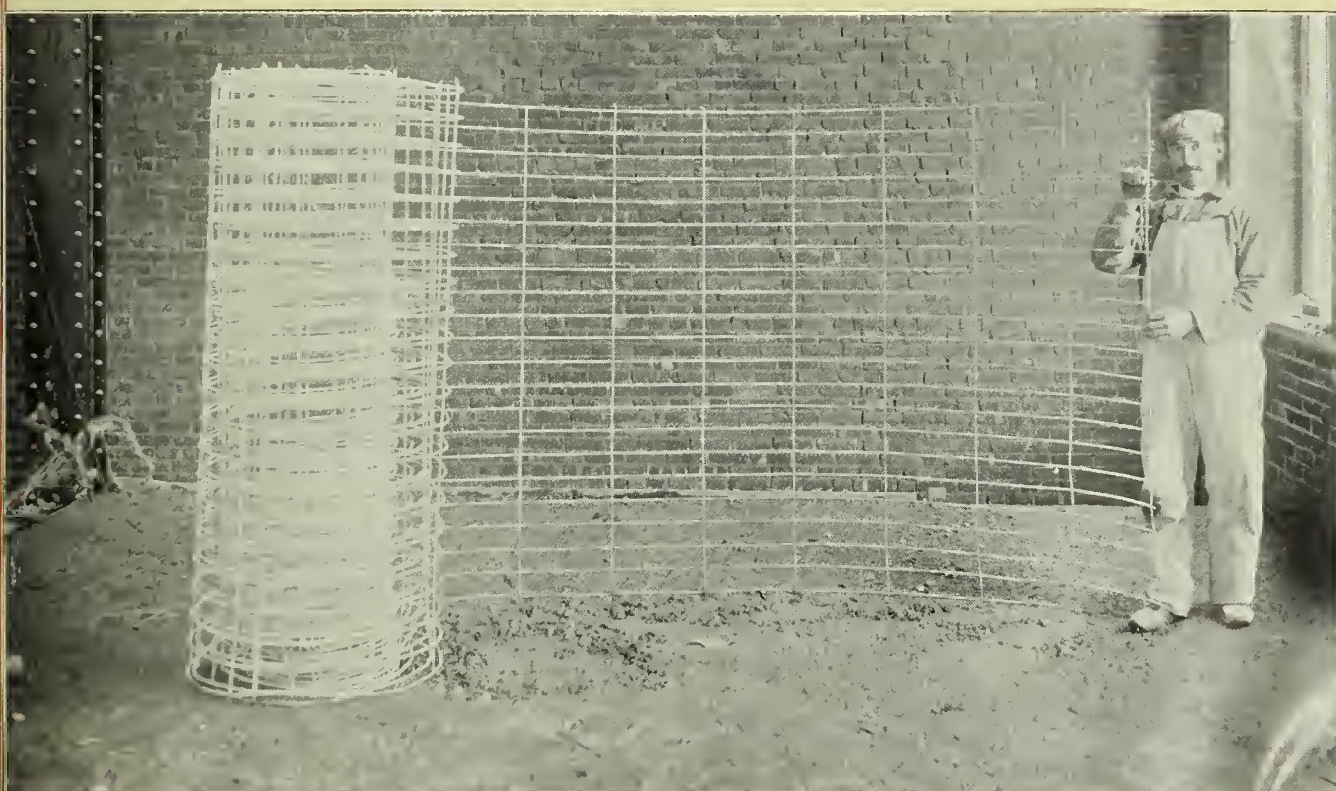
Bibliography.-

"The Roebling System for Floors and Walls" - Eng. News, July 18, 1895; "Concrete Metal Construction" - J. W. of Eng. S. Feb. 1901; "Forms of Concrete Reinforcement" - Iron Age Jan. 11, 1906; "The Roebling System of Fire-Proof Construction" - Roebling Construction Co., 121 Liberty St., N. Y. City.

3. Clinton Wire Cloth System.

This system is the one used by the Clinton Wire Cloth Company of Clinton Mass., who are the inventors and sole manufacturers of the metal used. The wire cloth used in

this system is the "Clinton Electrically Welded Metal Fabric." It is extensively used in the United States as a reinforcing material in nearly all kinds of reinforced concrete construction. Figure 12 is a cut showing a roll of the "Clinton Fabric" and Figure 13 is a cut showing the weld between the longitudinal and transverse wires.



A ROLL OF CLINTON ELECTRICALLY WELDED FABRIC.

Fig. 12

Electric Weld.

Fig 13.

Notice that it is impossible to detect the junction of the wires; in other words there is a perfect weld and it is a notable fact that tests made upon the fabric have proven that the wire invariably breaks at some other place than at the joint. Fabric made of No. 6 to No. 10 gauge (W. & M. gauge), drawn steel wire is used up to lengths of 300 feet. The wire can be used either plain or galvanized but most of the cloth put out by the manufacturers is galvanized. This is not done however to increase its efficiency in the concrete but to protect it from climatic conditions prevalent before the material is laid.

An important feature of the Clinton system is its flexibility whereby it is adapted to meet many requirements. Another point to its credit is the evenness of

the mesh insuring uniformity of strength throughout.

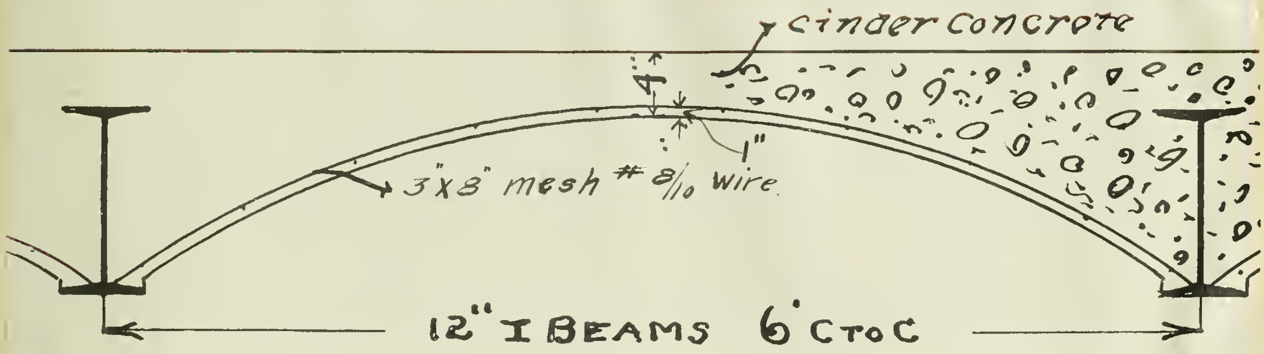


Fig. 14.

The floor construction is shown in figure 14. This is the class of floor authorized by the "Bureau of Buildings" of N. Y. City for use where there are loads of 350 pounds per square foot. The factor of safety is ten.

Several tests have been made by Ira. H. Woolson of the Mechanical Engineering Department of Columbia University. One floor of 15 foot span was heated to an average temperature of 1700°F. for four hours and then subjected on top and bottom, to a 1⅛ inch stream of cold water under 60 pounds pressure. After the test the plaster was nearly all gone, and

the concrete somewhat washed away but none of the reinforcing wire was exposed.

Among the many buildings in which the Clinton System was used are the "Maine Memorial Chapel", Annapolis, and the "Produce Exchange Bank Building", New York.

Bibliography:—

"Architects' and Builders' Pocket-Book" - Kidder; "Clinton Fire-Proofing System" - Clinton Wire-Cloth Co, Clinton, Mass.

4.- American System

The American System consists of a woven-wire fabric with plain round rods placed beneath, both being of high carbon steel. The use of high carbon steel is based on the argument that the efficiency of a reinforcing material depends upon its tensile strength and, high carbon steel has a greater tensile strength than either mild or medium steel. The manufacturers cite the following quotations from Prof. Talbot's Bulletin No. 1,

Tests of Reinforced Concrete," as substantiating their argument: "So far as strength of a beam is concerned, steel having a high elastic limit is advantageous." "Reinforcement as high as $1\frac{1}{2}$ per cent in steel of 33000 pounds per square inch elastic limit, and 1 per cent for steel of 55,000 pounds per square inch" elastic limit, may be used without developing the full compressive strength of the concrete." The American rods have an elastic limit of 60,000 pounds per square inch and the No. 9 wire of the fabric an elastic limit of 120,000 pounds per square inch. The standard styles are No. 7 or 9 carrying wire, both having No. 11 cross wires made to form 6"×6", 4"×12" or 4"×6" meshes. There are 200 linear feet in a roll of fabric the standard widths being 3, 4, and 5 feet.

Following is a table of tests made on wire used in the American System.

Tests by Prof. Talbot, U. of I.

	Area □-ins.	Ult. Str.-lbs	E.L.-lbs./□ins.
Av. of 8 tests on No. 9 Wire	.017	146,000	124,000
" " " " " " 11 "	.010	140,000	118 000

Among the many advantages claimed for the American System are:

1. Ideal distribution of metal, thereby taking advantage of the full compressive strength of the concrete. From a lecture by E. P. Goodrich, June 12, 1906 the following is taken. "An increase in carrying power of 250 per cent was secured in beams only 3 weeks old through the use of rod reinforcing which added less than 10 per cent to the cost of the beams."
2. Continuous bond. The adjoining widths of fabric are connected by means of hooks as shown in figure 15.
3. Cheapness. The high efficiency due to high elastic limit reduces the amount of material required.

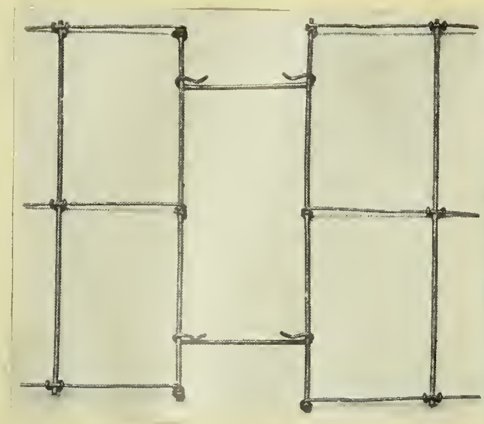


Fig. 15—"Am. Hook."

The results of a test on an "American" floor made by the N.Y. Building Department are given below. The area of the floor was 77 square feet, the beams being 14 feet long and spaced 5ft. 6ins. center to center.

was heated to 1700°F for 4 hours, after which a 1½ inch fire stream under 60 pounds pressure played for 5 minutes upon both top and bottom.

Test Table.

Load-lbs/□'	Deflections–inches		
	East	Centre	West
150	0.10	0.025	0.125
300	0.125	0.050	0.10
450	0.175	0.075	0.175
600	0.20	0.125	0.175
600	0.175	0.200	0.175
450	0.125	0.175	0.20
300	0.150	0.10	0.175
150	0.075	0.125	0.150
0	0	0.10	0.125

The following recommendation was made by Mr. Ewing, Engineer of the tests: "In consequence of the good record made by the floor during the various investigations, the various conditions of Section 106 of the Code having been fulfilled I would respectfully recommend that the structure be allowed up to spans of 5 feet c.-c. with the usual allowable variable distance

of 6 feet when constructed as tested."

An example of the American system is to be seen in the Butler Bros. Building at Minneapolis, Minnesota, which has 13 acres of floor space.

Bibliography:--

"Fire Tests of Fire-Proof Floors by N. Y. Bldg. Dep't," Eng. News 5/29/02; "American System of Reinforcing for Concrete Construction, Chicago, Ill."

5. Lock Woven-Wire Fabric

This form of reinforcement is a netting and is used in the same manner as other woven-wire reinforcements. The fabric is put up in rolls 52 inches wide and 300 feet long, the ultimate strength of the component wires being about 116,000 pounds per square inch. The material is furnished by H. N. Hight & Co. of N. Y. City in any size mesh required and of any gage wire. This reinforcement possesses the same advantages as all net reinforcement,

the particular characteristic being a lock-wire tie at each connection, which is intended to make a good joint. A description of tests on a Lock Woven Wire floor is given in the Eng News for May 29, 1902. Practically the same recommendations were made of it as for the American floor.

III. EXPANDED METAL.

The Expanded Metal system is sometimes considered as a net system, but although it might be called a form of netting, on account of its general make-up being altogether different from those commonly classified as netting, we will put it in a class by itself.

Expanded Metal is made from sheet steel cut with the grain and expanded into diamond-shaped meshes, the finished product being from 8 to 12 times wider than the sheet steel. The material varies in thickness from No. 27 gauge (.017 inches) to No. 4 gauge (.23 inches) and the sizes

of such sheets are $10\frac{1}{2}$ feet by 6 or 4 feet and 8 feet by 6 or 4 feet, the sheets being joined together in construction by simply lapping. Cinder concrete is used for floors on account of its lightness and resistance to fire.

Expanded Metal is both a longitudinal and transverse reinforcement but does not add anything to the crushing strength of the concrete. Figure 16 shows the general form of this material. Notice that the bounding sides of each mesh are not in the same plane, this irregularity increasing

Fig. 16

the bond of the metal to the concrete. Expanded Metal has been manufactured and used for reinforcing concrete for fourteen years, is now probably used more extensively in concrete floor construction than any other reinforcing material, and, on the whole,

has proven very satisfactory. To it are accredited the advantages of bond, strength, adaptability, durability, etc. possessed by other fabrics and besides it is comparatively light and easily placed. The main disadvantage ascribed to it is, that the larger meshes such as are suitable for floors cannot be purchased, but are used in construction by only licensed companies. Eleven such companies are in the United States and one in Toronto, Canada. And as there is no competition Expanded Metal reinforcement is perhaps a little more expensive than most others.

There have been many tests made on this kind of construction and the results of these show sufficient strength for all ordinary purposes. Following are the results of tests as given in the "Journal of the Association of Engineering Societies" for February, 1901.

Table of Results.

No of Test	Length of Span	Thickness, inches	Mixture of Concrete: Cement	Sand	Cinder	Age-days	Equivalent Distributed Load #/□'	Deflection-inches	Size of Metal.
1	4'-1½"	3"	1	2	5	30	2333	0	3" mesh #10 gauge
2	4'-1½"	3"	1	2	5	31	2354	0	"
3	5'-2"	3½"	1	3	6	30	715	1/16	"
4	4'-0"	3½"	1	2½	5	30	1750	0	"
5	6'-0"	3½"	1	2	5	30	1100	1/4	"
6	6'-0"	4"	1	2	Rock 6	28	850	1/16	"
7	5'-4"	4"	1	3	6	30	914	5/16	"
8	5'-4"	6"	1	3	6	30	914	0	"
* 9	11'-0"	6"	1	2	5	30	360	9/64	2 Sheets 3"-#10 gauge
10	4'-0"	2½"	1			30	26	Broke	No Metal
11	4'-0"	2½"	1			30	256	Broke	3" Mesh #10 Gauge

The cement used was American Portland.

*When load was removed $\frac{3}{64}$ inches deflection remained.

Among the examples of Expanded Metal reinforcement is the "Office Bldg. of Swift and Company," Union Stock Yards, Chicago containing over 100,000 sq. feet of Expanded Metal floors with spans of 19 feet.

CONCLUSION.

We have seen, to some extent, how concrete is reinforced with steel to obtain a structural material for general use in nearly all kinds of construction. As yet reinforced concrete is in its infancy and at its present rate of growth it bids fair to become one of the greatest, if not the greatest, material for construction purposes.

After a consideration of the numerous methods of reinforcing concrete, each one having certain advantages, we would not recommend any one method above all others in all purposes. Some methods are especially adapted to particular kinds of construction while a combination of two or more methods may sometimes be used to the greatest advantage. Probably no general rules can be laid down except that the concrete should be reinforced in such a manner as to

develope its full compressive strength. For any particular construction the way in which the concrete is to be reinforced is a matter of judgment derived from experiment, common sense and experience.